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In situ radiation influence on strain measurement performed by Brillouin sensors

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ABSTRACT

A new approach is proposed to monitor *in situ* gamma radiation influence on Brillouin optical fiber extensometers. Experimental results are illustrated with two fiber samples under gamma radiation up to total dose of about 600Gy. The Brillouin frequency shift has poor sensitivity at such radiations level, neither the spectral Brillouin signature nor its dependence with strain. Meanwhile, propagation losses increase under radiations, with an amplitude linked to fiber dopants. The target application is Nuclear Wastes Repository Monitoring where high doses are expected. UV radiation preliminary tests show that compaction phenomenon may occur at such high doses, inducing Brillouin frequency shift up to 20 MHz.

Keywords: distributed Brillouin fiber sensor, gamma radiation, strain, radiation induced attenuation

1) INTRODUCTION

The nuclear industry has shown the possibilities offered by fiber optic technology for both data transfer and sensing applications […]. Distributed strain measurements may be used for structural integrity monitoring of the reactor containment buildings or nuclear waste repository. Continuously distributed fiber sensors based on Brillouin scattering are widely used to monitor strain and temperature of various civil engineering structures […]. The implementation of optical fiber sensors in radiative environments such as Nuclear Waste Repositories requires more detailed understanding of the influence of radiation on the optical fiber properties.

The main effect of radiation on optical fiber is well known. The increase of optical attenuation called, Radiation Induced Attenuation (RIA), depends on optical fiber dopants, on radiation levels, total doses as well as dose rate. Regarding Brillouin scattering, published *post mortem* measurements showed that distributed Brillouin sensor (DBS) is gamma-rays tolerant up to total doses of about 100kGy in standard single mode optical fibers [1]. However, for Nuclear Waste Repositories, total doses may reach 10^7Gy (corresponding to the monitoring of structures hosting high level wastes during a century). Given optical power densities of the pump lasers used to induce stimulated Brillouin scattering and the well-known photobleaching effect, it seems mandatory to perform *in situ* measurement of both Brillouin scattering and its dependence with strain and temperature.

In this paper, we present our approach based on a special fiber coil to monitor the distributed fiber Brillouin strain (DFBs) dependency during the irradiation.

2) EXPERIMENTAL PROCEDURE

a) Experimental set up

The gamma irradiations were performed at CEA-DAM facilities. A ^{60}Co (~1MeV) source was used at room temperature with a typical dose rate of $10 Gy.h^{-1}$. Figure 1(a) presents the experimental setup used to validate the feasibility of *in situ* measurements of Brillouin scattering strain dependency. RIA measurements were also performed at specified wavelengths (1310 or 1550nm) and in larger spectral range [850-1700 nm]. The uncertainties on total dose measurement are estimated to be within 10%. Temperature was monitored thanks to a compact temperature recorder.

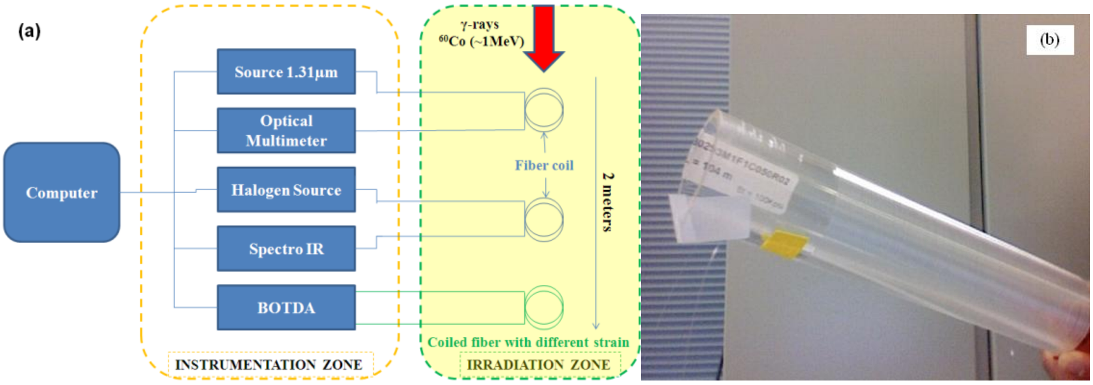

Figure 1. (a) Experimental set up, (b) Fiber coiled on quartz tube.

Stimulated Brillouin scattering was measured with a BOTDA [2] commercially available instrument operating at 1.55µm. Measurements were performed on each sample every 30 minutes with a pulse duration set to 5 ns equivalent to a spatial resolution of typically 50 cm.

b) Preparation of optical fibers samples

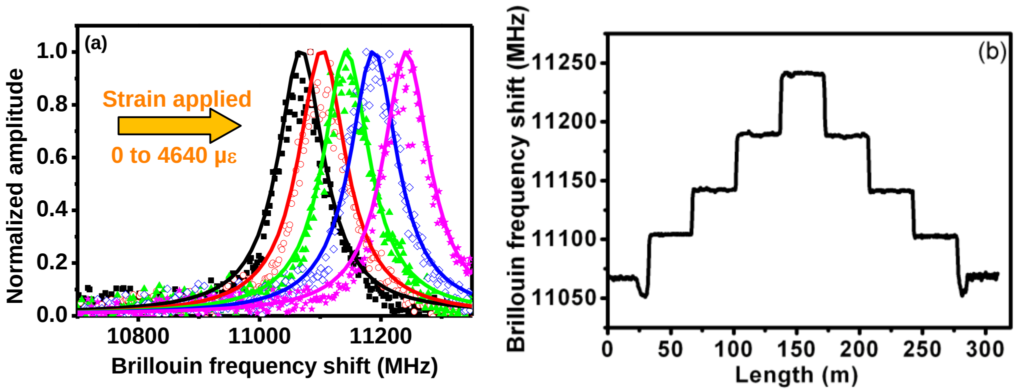

Figure 2. (a) Measured Brillouin spectra along F-doped fiber coiled under different stress. (b) Maximum Brillouin frequency shift along the same optical fiber sample.

We have tested two different types of single mode optical fibers samples: SMF28™ and a silica core fiber with fluorine doped optical cladding made by iXfiber SAS. The tested fibers samples were about 300 meters long, this length being representative of Nuclear Wastes Repository cells dimensions. They were coiled on a 9cm diameter quartz tube, material chosen for its transparency regarding gamma radiation illustrated in Figure 1 (b). During the coiling of the fiber, various known masses were applied to several sections of about 20 meters [3]. The mechanical strain ε transmitted to the sample can be expressed by: $\varepsilon=(m*g)/(2*S*E)$, where m*g, S, E are respectively the weight, surface of the main section of the optical fiber sample and its Young's modulus.

Such a distribution of mechanical stress along the fiber enables investigating possible gamma influence on strain dependency (C_ε) of Brillouin frequency shift ν_B: $\nu_B=C_\varepsilon*\varepsilon+C_T*\Delta T$.

Measured DFBs before irradiation is illustrated in Figure 2 for the fluorine doped fiber. The strain coefficient associated with the sample is derived immediately which enabled *in situ* measurements during irradiation.

3) EXPERIMENTAL RESULTS

a) Gamma radiation effect on Brillouin properties

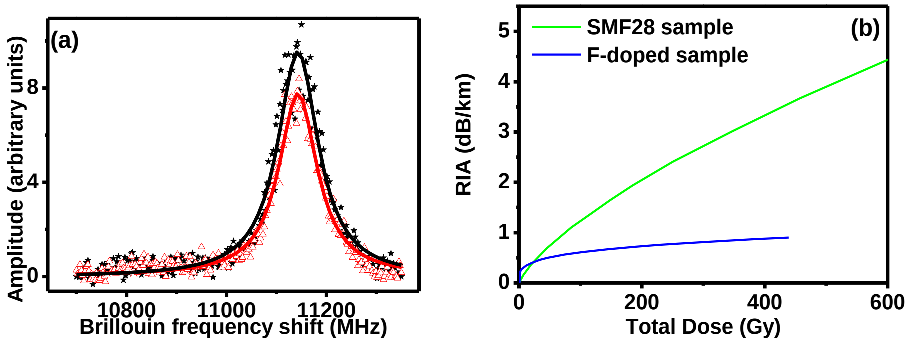

Figure 3. a) Brillouin spectrum measured in the F-doped optical fiber before (black curve) and after (red curve) gamma irradiation. (b) Radiation induced attenuation as a function of total doses in the two optical fiber samples at 1.31µm.

The Brillouin spectra and its strain dependency remained stable during the gamma irradiation up to 600Gy total doses as illustrated in Figure 3(a). Similar results are observed on the two different optical fiber types. For the two samples we retrieved $C_{\varepsilon(SMF28)}$=0.049MHz.$\mu\varepsilon^{-1}$ and $C_{\varepsilon(F\text{-}doped)}$=0.040MHz.$\mu\varepsilon^{-1}$ before and after irradiation.

These experiments validate the experimental setup built for the *in situ* characterization of radiation effects on Brillouin scattering properties in silica-based optical fibers.

In the investigated dose range, the main radiation effect regarding the DFBs performances is the reduction of the signal noise ratio due to RIA on the optical fiber sample. We have monitored the RIA change during the irradiation. It revealed different kinetics of RIA depending on the core composition fiber sample Figure 3 (b). At the wavelength 1.31µm, the optical losses in the F-doped optical fiber is less than 0.75dB.km^{-1} after 450Gy while radiation induced attenuation is about 3.5dB.km^{-1} for the germanosilicate sample. Such results agree with previous studies on the influence of core composition showing pure-silica core and F-doped optical fibers are the best candidates as radiation-tolerant waveguides [4].

The measurements revealed the influence of the photobleaching effect [5] on the RIA level for both fibers. This effect confirms the good interest of *in situ* strain measurement of the Brillouin scattering regarding the optical power densities of pump laser injected in the optical fiber sample during the irradiation.

As mentioned, the target application is Nuclear Wastes Repository Monitoring where high doses are expected: 10^7Gy is the expected integrated doses to be received by sensors during the exploitation period, namely a century. ^{60}Co is not suited to simulate such high doses. It has been shown that UV radiation can be used as an interesting hardness assurance tool with some advantages in terms of security and access to radiation facilities [6].

b) Towards high doses: experimental result under UV irradiation

In general, high gamma dose testing requires major investment in terms of equipment and costs. In this context, we showed that UV radiation can be used as an interesting hardness assurance tool to compare the sensitivities of different fiber types, we showed this kind of experiment can reveal the high sensitivity of some doped optical fibers, with some advantages in terms of security and access to radiation facilities.We performed *post mortem* study of UV irradiation influence on the Brillouin frequency shift in a single mode SMF28™ and a single mode highly germanium doped fiber. We have shown that UV radiation may induce a significant Brillouin frequency shift change owing to a compaction phenomenon depending on optical fibers [7]. The photosensitive fiber shows a permanent change in the Brillouin frequency shift of 20MHz (Figure 4) whereas SMF28™ properties remain quite stable.

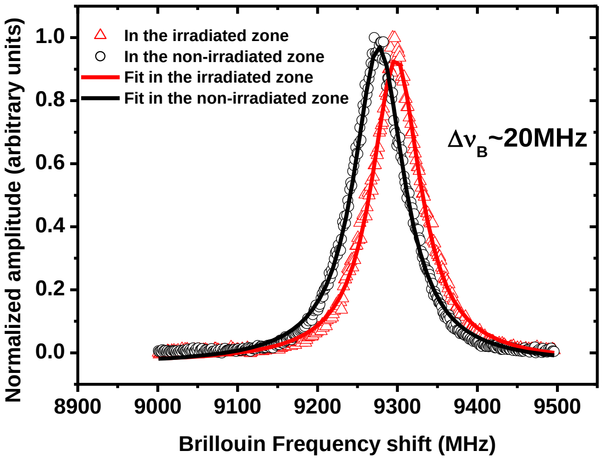

Figure 4. Brillouin frequency shift observed for the UV irradiated zone compared to the non irradiated zone in the highly Ge-doped fiber.

CONCLUSION

We designed and validated a new approach to perform *in situ* measurement of DBS radiation influence. Fiber samples were coiled with different strain and exposed to gamma radiation up to total dose of about 600Gy. In these conditions, the Brillouin frequency shift is not modified by radiations: radiation induced attenuation is the main process. However the amplitude of RIA depends on the fiber sample (F-doped one is better) as well as on the injected power level. To anticipate high gamma doses, UV radiations were performed. *Post mortem* Brillouin spectrum measurements reveal that the compaction phenomenon appears at high dose level [8] and induces a shift of the Brillouin frequency as large as 20 MHz. Further investigations will be performed including UV exposure and high gamma dose irradiation representative of the environment associated to Nuclear Wastes Repository.

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